Written Testimony of

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The Need for Physical Sciences Research at NASA

Introduction

Chairwoman Hutchison, Ranking Member Nelson, and members of the committee, thank you for inviting me to testify today. My name is Peter Voorhees. I am the Frank C. Engelhart Professor and Chair of the Department of Materials Science and Engineering at Northwestern University. I was a member of the National Research Council Space Studies Board and Chair of the Committee for Microgravity Research. Through my tenure as Chair I have become familiar with the microgravity program and many of the areas within the physical sciences that are at the core of NASA's human exploration effort.

I believe that a strong physical sciences research program is crucial to both capitalizing on NASA's significant past investment in this area and to enabling the human spaceflight program. In 2004 President Bush provided a clear vision for NASA's human spaceflight effort and NASA has fully embraced the goal of returning humans to the Moon and eventually sending humans to Mars. However, to accomplish these goals research in the physical sciences is necessary to gain a more complete understanding of effects of microgravity on a wide range of processes as well as develop a variety of technologies to ensure the safety and success of these missions. Only by supporting an ongoing physical sciences research program will NASA be able to avoid failures that could have been anticipated by an ongoing physical sciences research program and to implement the President's vision in the most cost-effective and rapid fashion.

The Development of the Physical Sciences Research Program

The evolution of NASA's physical sciences research program provides important lessons for how to formulate a successful research program to enable human space exploration. NASA's physical sciences research program began as the materials processing in space effort during the Skylab era. The program was singularly focused on performing experiments in space. As a result, many of the experiments were ill-conceived and few yielded new insights into the physical phenomena that were operative in space or impacted their respective scientific communities. In the early 1990s a new paradigm for research was initiated in the fluids, materials, combustion and fundamental physics research areas. In order to attract the best researchers, a concentrated out-reach effort was undertaken and a rigorous peer review system was instituted. In addition, a large ground-based research program was created that ensured that ideas were refined and scientific questions identified that could be answered only through space flight experiments. As a result the "shoot and look" approach to performing experiments during the Skylab era was replaced by carefully conceived hypothesis driven experiments. At its peak there were approximately 500 investigators in the program and it supported 1700 research students.

The 2003 National Research Council (NRC) study "Assessment of the Directions in Microgravity and Physical Sciences Research" found the quality of the investigators in the program to be excellent. On the basis of an analysis of the citations of the papers published, prominence of journals in which the papers appeared, the influence of the research on the content of textbooks, documented influence on industry and the quality of the investigators in the program, we found that the microgravity program has had a significant impact on the fields of which it was a part. For example, 37 members of the fluids program were fellows of the American Physical Society, the materials science program produced some of the most highly cited papers in the area of solidification and crystal growth, and the fundamental physics program was funding six Nobel laureates. Many billions of dollars were invested in creating this successful and influential program.

NASA should take great pride in the creation of this high quality physical sciences research program in the fluids, combustion, materials and fundamental physics areas. It evolved into one of the jewels in NASA's crown. With the growth in the quality of the program NASA became the primary source of funding for research in areas such as crystal growth, low temperature physics, and low Reynolds number and interfacial fluid flow making NASA stewards of these important and broad scientific areas.

In early 2001 it became apparent that the International Space Station (ISS) program was facing major cost overruns. These financial constraints led to a major reduction in the microgravity research that had been planned for the ISS. Many of the experimental facilities that were planned were either reduced in size or delayed and the number of crew aboard the ISS was cut, making it difficult to perform experiments during the construction phase of the project. As a result, flight experiments were delayed or effectively cancelled. The catastrophic loss of the Columbia orbiter in 2003 placed even more serve restrictions on the ability to transport samples and experimental equipment to and from the ISS.

The challenges posed by these recent events, the need to retire the Shuttle by 2010, as well as develop the Crew Exploration Vehicle have placed great pressures on NASA's budget. These financial constraints have resulted in a major reduction in the size and scope of the physical sciences research program. For example, with breathtaking speed and no external input NASA eliminated the Office of Biological and Physical Research, and the Physical Sciences division within the office. The number of principal investigators has been reduced to less than 100 with still more reductions proposed. NASA’s physical sciences research effort is on the verge of elimination. FY07 is the last chance to keep physical sciences research at NASA alive.

Rationales for Physical Sciences Research at NASA

The raison d'être for physical sciences research at NASA lies in both the past and future. Since 1990 NASA has been investing significant resources, measured in the billions of dollars, in developing and maintaining a community of high quality researchers in the microgravity sciences arena. The focus of this research is to use the microgravity environment to study a broad range of physical phenomena. The research spans from the basic to the applied, and will continue to impact both the scientific communities of which the research is a part as well as industry. As a result of the rigorous peer review of this research, important discoveries have been made in fields ranging from the wetting and spreading dynamics of fluids on surfaces to relativity and precision clock experiments. Moreover, many of the space flight experiments that flow from this program require the unique microgravity environment that is provided by the ISS and thus make use of a national asset that has been very costly to create. Ending the physical sciences research will squander the investment made in building the physical sciences research program and negatively impact the ability to perform high quality research on the ISS.

Just as important as this past investment is the likely impact of the physical sciences program on the future of NASA’s human exploration effort. A vibrant physical sciences research program is the key to successfully accomplishing the President’s Vision for Space Exploration, since important technology required for space exploration is controlled by gravitationally related phenomena that are poorly understood. This lack of understanding hampers the design of a vast array of devices such as those for heat transfer, the prevention and detection of fires, fluid handling, controlling the transport and movement of Lunar and Martian soils, and materials repair such as brazing and welding, among many others. The need for research in these areas is discussed in detail in the NRC report “Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies.” Given the central importance of these areas in fostering the human exploration of space effort, the impact of a physical sciences research program on one of NASA’s central missions could thus be profound. As illustrations, I shall focus on two such examples: heat transfer systems and fire prevention and detection.

Thermal control is critical for spacecraft; excess heat must be rejected into space and moved from one section of the craft to another. In the past NASA relied on single-phase heat transfer systems, for example systems that involve only a liquid to transfer heat. However, there are clear advantages of employing systems that involve both a liquid and vapor (two phases), such as those used on the earth. This allows one to employ the significant amount of heat required to transform a liquid to a vapor or a vapor to a liquid in the heat transfer process. This significant heat of vaporization or condensation allows the heat to be transferred in a far more efficient manner than with a single-phase system. The successful operation of such systems on the earth frequently requires that the less dense vapor sit above the more dense liquid which, due to the presence of gravity, occurs naturally in a terrestrial environment. However this density driven stratification would not be present in space. This is but one of the many challenges of using such systems in space. Nevertheless, the advantages of using such a system in a spacecraft are significant. Given the enhanced efficiency, a multiphase heat transfer system would save considerable space and mass. Heat pipes have also been proposed as possible heat transfer devices. These have the advantage of being completely passive where the motion of the fluid is driven by the surface tension of the liquid, but they also involve evaporation and condensation to transfer heat.

The central reason why heat transfer systems that involve multiphase flow are not more commonly used in spacecraft is that the dynamics of flow in systems with more than one phase, such as a vapor and liquid, in a microgravity or partial earth's gravity environment are not well understood. A ground-based and flight program focused on the dynamics of flow in these multiphase systems could provide the insights to allow these higher efficiency devices to be used in the human spaceflight effort. While there are constraints on the mass and space available in the limited-duration environment of the Shuttle or ISS, the constraints placed on long-duration flights to Mars or even the Moon are even more stringent. Thus, the availability of high efficiency heat transfer devices, that occupy less space and have a smaller mass than existing devices, would open up much needed space for food and water. It is only through research in this area that these devices will be embraced by the spacecraft engineering community.

A second example of the importance of physical sciences research is in preventing and detecting fires in a reduced gravity environment. We have had thousands years of experience detecting and fighting fires on Earth. In contrast our experience with combustion phenomena in microgravity or partial Earth's gravity is limited to at most fifty years. As a result, our understanding of the flame propagation issues that impact spacecraft safety is very limited, and research in this area continues to uncover new and unexpected results. For example, flames can spread along surfaces in the opposite direction to that on earth, flames extend over electrical insulation 30 to 50 percent faster in microgravity than under normal conditions, and smoldering under microgravity conditions is less bright and more difficult to detect than on the ground. All of these results were determined from basic research conducted in only the past 10 years and have had a documented effect on the fire fighting procedures on spacecraft. Given the limited number of experiments performed in microgravity and the surprising results thus produced, there is much still to be learned.

Although fires on a space craft are an unlikely event, if one should occur it could be catastrophic not only for the mission but for the entire human exploration of space effort. The absence of any safe refuge on a spacecraft and, possibly, lunar base makes detecting and preventing small fires essential. Moreover, the design of lunar habitats that mitigate the effects of possible fires requires knowledge of how fires propagate in structures in partial Earth's gravity. Physics based simulation codes exist for fires in Earth-based structures, but none exist for micro or partial gravity environments. Given our lack of understanding of how fires behave in microgravity environments and the critical importance of this to the human exploration effort, I can think of few stronger rationales for a vigorous combustion research program. Such a program must involve an active ground-based program and, due to the long duration of many combustion experiments, ready access to the ISS may be required.

Going Forward

In order to leverage the past investment in physical sciences research and to ensure a successful future for the human exploration effort it is crucial that a broad spectrum of physical sciences research in NASA be retained. The importance of continuity in a research program cannot be overemphasized. Continued support of this community is essential in engaging the best researchers, producing the students interested in working with NASA upon graduation, and performing the ground-breaking research that is essential to accomplishing NASA's human spaceflight goals. The level of support needed for this continuity is quite modest given that a cadre of 250 investigators each of whom requires $130K would lead to a $32.5M per year program, a very small investment compared to the $1B of the former Office of Biological and Physical Research. This represents the minimum support needed to keep a physical sciences research program alive at NASA. Many researchers have recently had their programs terminated. If this support is not made available in the very near future these scientists will be reluctant to return to microgravity research and the remaining researchers will also likely leave the program. As a result NASA will find itself in the same position as it was in the late 1980s: without an organized and influential microgravity research program. Unfortunately, NASA will never have the time or the resources to recreate a physical sciences research community. Therefore it is absolutely imperative that NASA fund physical sciences research at no less than $32.5M for FY07.

To avoid many of the pitfalls of the past, it is essential that the program involves both ground-based research and spaceflight experiments. One of the crucial lessons of the early microgravity program is that only through the testing and refinement that is possible with ground-based theoretical and experimental research can experiments be performed in space that will yield reliable results. It is essential that both the ground-based and spaceflight research be rigorously-peer reviewed.

The future of research at NASA is being threatened as never before. It is important to realize that funding physical sciences research will not diminish in any way NASA's future plans for human exploration. Rather it will be an essential enabler in this effort. Finally, continuation of the funding will allow NASA to reap the benefits of many past years of funding of high impact research that is focused on gravitationally related phenomena.

Thank you very much for the opportunity to testify today. I look forward to responding to your questions.